

CRL X-RAY TUBE

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A novel types of X-ray tubes with refractive lenses are proposed. CRL-R X-ray tube consists of Compound Refractive Lens-CRL and Reflection X-ray tube. CRL acts as X-ray window. CRL-T X-ray consists of CRL and Transmission X-ray tube. CRL acts as target for electron beam. CRL refractive lens acts as filter, collimator, waveguide and focusing lens. Properties and construction of the CRL X-ray tube are discussed.

Introduction

There are four devices for generation X-rays: X-ray tubes, synchrotrons, high temperature plasma, X-ray lasers. X-ray tubes are the most common and available laboratory X-ray sources. X-ray tube is a vacuum triode under high voltage (up to 200 kV). X-ray tube typically consists of a vacuum glass tube, two electrodes (cathode and anode), magnet lens and the X-ray window, made of low absorbing materials (Be). X-rays are generated by decelerating focused electron beam in the target. Target is a massive metal anode or a thin film deposited on the surface of X-ray window. There are reflection and transmission X-ray tubes with different target type (Fig. 1). The reflection tube or directional tube includes a massive metal target. Reflection X-ray tubes offer higher output and one of the most powerful X-ray transmission tube is a rotating anode X-ray tube. Rotating anode of X-ray tubes are made of refractory targets. X-ray anodes are typically manufactured with a substrate of Mo alloys. The transmission type X-ray tube comprises a target and a filter material. A microfocus X-ray tube that can generate X-rays with the focal spot size less than 5 microns has been demonstrated using carbon nanotube field emitters. The target has at least one element which produces X-rays as being excited. The thickness of the filter material is at least 10 microns and less than 3 millimeters.

X-ray tubes construction depends on methods of generating X-rays (liquid, reflection or transmission type of anode), to methods of producing beam of electrons (thermal or cold field emission, radioactive), type of anode (stationary, rotating), vacuum system (sealed, open), cooling system (water, air, oil), focal size (macro, micro and nanofocus), shape of the focus (ring, circle, line), time of emission (continuous, pulsed), magnet lens, spectrum, lifetime and others.

X-ray tubes are experimentally used with collimators, monochromators, filters and optical elements—lens, grating, waveguide, mirror to control properties of X-ray tube radiation. Spectrum of the X-ray tube consists of a continuous bremsstrahlung spectrum and discrete characteristic lines. X-ray tube spectrum depends both on energy of electron, focal spot size (length, shape), and target properties (chemical elements, angle thermal conductivity, density). For example, the filter material for characteristic lines should have a K-edge absorption energy higher than the $K\alpha$ and is lower than the $K\beta$ emission energies of target material.

Novel refractive X-ray optics based on many refractive surfaces (Compound Refractive Lens, CRL) has received a great development over the past 20 years. Today it is known more than a dozen types of

compound refractive lenses CRL (one-dimensional and two-dimensional parabolic lenses, lens-alligator, Clessidra, microcapillary lens, adiabatic lens, 3D lens, etc.) [3]. Typical CRL lens is an array of biconcave microlenses, centered on the same optical axis. CRL lens may contain from tens to several hundreds of individual microlenses, made of materials with low atomic number. These lenses have high transmittance (up to 18%), short focal distance (up to cm), are compact in size (the radius of the microlenses 500 – 5 μm), shape appropriate for heat dissipation and alignment. These lenses used for synchrotron sources of the third generation and for microfocus X-ray tubes [4].

The main goal of the report is to discuss the possibility use of CRL structures as the anode or window (Fig. 1) of the X-ray tube. Two novel types of X-ray tubes with refractive lenses are proposed. CRL-R X-ray tube uses a compound refractive lens CRL as X-ray window of reflection X-ray tube. CRL-T X-ray tube uses a compound refractive lens as target for electron beam of transmission X-ray tube.

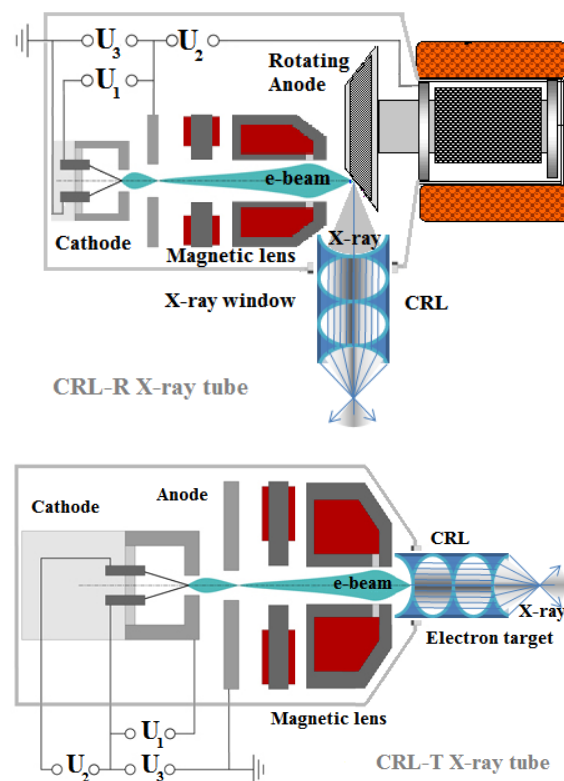


Fig. 1. Schematic view of CRL-R X-ray Reflection tube and CRL-T X-ray Transmission tube on the base of Compound Refractive Lens CRL.

CRL-RX-ray tube

CRL can be integrated into the reflection (R) X-ray tube as a X-ray window in vacuum shell and may produce image of the focal spot or collimated beam.

Lens-maker's equation shows that distance from lens to object L depending on distance from lens to focal spot of X-ray tube and CRL focal length F:

$$L(\lambda) = \frac{F(\lambda)S}{S - F(\lambda)} \quad (1)$$

The focal spot of anode is at a distance of 0.5 - 1 cm from the X-ray window. So the focal length of the CRL should be less than 1cm for producing real image and converging beam. If focal length F is less than S CRL produces virtual image and diverging beam. If focal length F is equal to S CRL acts as collimator. Equation (1) is valid only for thin lens approximation. Thick short focal CRL has a length M depending on radius R and number of individual microlenses N. Minimal distance between the source and its image is equal to four focal length 4F and for the maximum power of CRL lens. The maximum power of the CRL lens length of a lens M is equal to two focal lengths F. Thus it is possible estimate the parameters of CRL lenses for different wavelengths and radius generated microbeams:

$$\begin{cases} L = 4F(\lambda, R, N) = \frac{F(\lambda, R, N)S}{S - F(\lambda, R, N)} \\ M = 2F(\lambda, R, N) = 4RN \end{cases} \quad (2)$$

Due to chromatic and spherical aberrations CRL lens performs spectral filtering. Focal length of CRL depends on X-rays energy:

$$dF = \frac{2F(E)dE}{E} \quad (3)$$

The X-ray spectrum at the exit of refractive lenses is determined by a source of radiation, spectral functions of absorption and refraction coefficient for lens material, geometrical parameters of a lens. It results to spatial separation of focal spots for "high-energy" and "low energy" part of aX-ray spectrum. For "low energy" part of a spectrum the aperture of a refractive lens is small due to absorption. For a "high-energy" X-ray spectrum the aperture of a lens is equal to the radius of a lens diaphragm that results to significant spherical aberration.

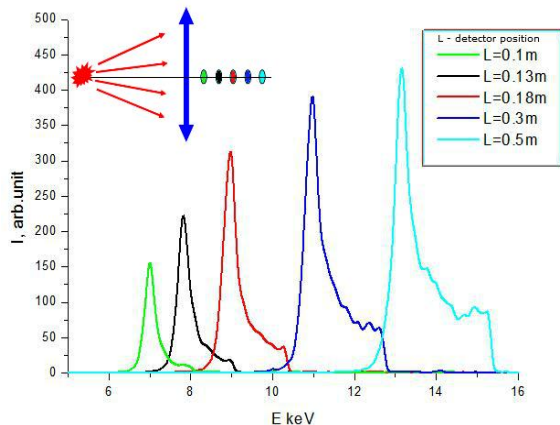


Fig. 2. Spectral distribution of X-ray radiation in focal spots for microcapillary refractive CRL lens.

3-D ray tracing simulations for spectral distribution in focal spot were made. The quantity of rays was accepted equals to 10^6 . The microcapillary CRL X-ray lens has radius 100 microns and 70 individual polymer lenses. The results of ray tracing simulations of spectral distribution is shown in Fig. 2.

The spectral width of the peak is equal to $\Delta E = 1$ keV and depends on distance from the lens. Thus the X-ray tube with integrated CRL lens works as tunable X-ray source (Fig. 2).

CRL-TX-ray tube

CRL-T X-ray tube is a transmission type CRL X-ray tube. CRLs can be integrated into the X-ray tube as target for electron beam. Electron beam bombards and penetrates to the center of the first few microlenses of CRL structure. The process of the birth of X-ray photons will occur in the small area of first microlenses. The size of the active area is limited in space. Ray tracing simulations with supercomputer SKIF BSU shows that for generation of collimated microbeam the active area should be several millimeters in length and several microns in diameter (Fig. 3). First lens define generated X-ray spectrum and can be made from a metal due to high level of radiation and heatload. Other lens may be liquid for tunable CRL lens. The CRL lens works as waveguide for the generated X-rays. The parameters of the CRL structure define the spectral and angular characteristics of the X-rays in the same way as for CRL-R X-ray tube.

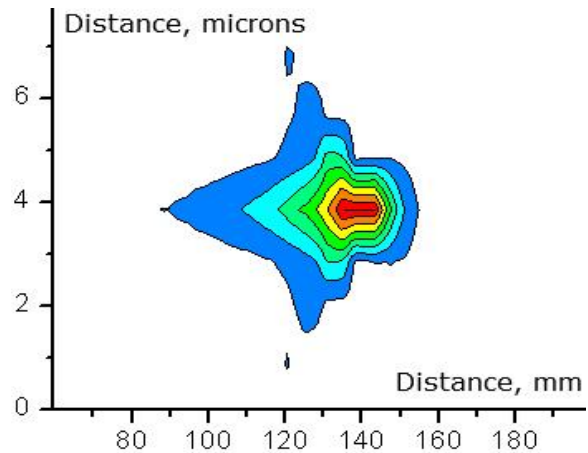


Fig. 3. Intensity distribution in focal spot of CRL lens.

Conclusion

New types of X-ray tube CRL-type is proposed. This tube is combine X-ray tube by modifying its anode or X-ray window by using compound refractive lens CRL. Possibilities of CRL-R and CRL-T X-ray tube depends on CRL properties. A tunable source on the base of CRL X-ray tube can be developed.

References

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